Summary of PS Module Irradiation

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Seven modules prepared and irradiated:

- Mixture of module types: 5 B-chip, 2 A-chip, 4 AMS, 3 IZM, 5 CIS, 2 new Tesla.
- All modules were "almost production quality" (except for one high IDDA chip).

Summarize lessons and first results:

- First time that we have taken a selection of modules from three sites and connected them together to make a system. Some lessons from this.
- Show some first results on behavior of threshold tuning versus dose, behavior after re-tuning, TOT versus dose, and a comparison of CIS and Tesla modules.
- Next step is to re-tune and characterize the modules in the lab. This will allow much more careful comparison of pre-rad and post-rad performance.
- Need to decide on an annealing protocol !

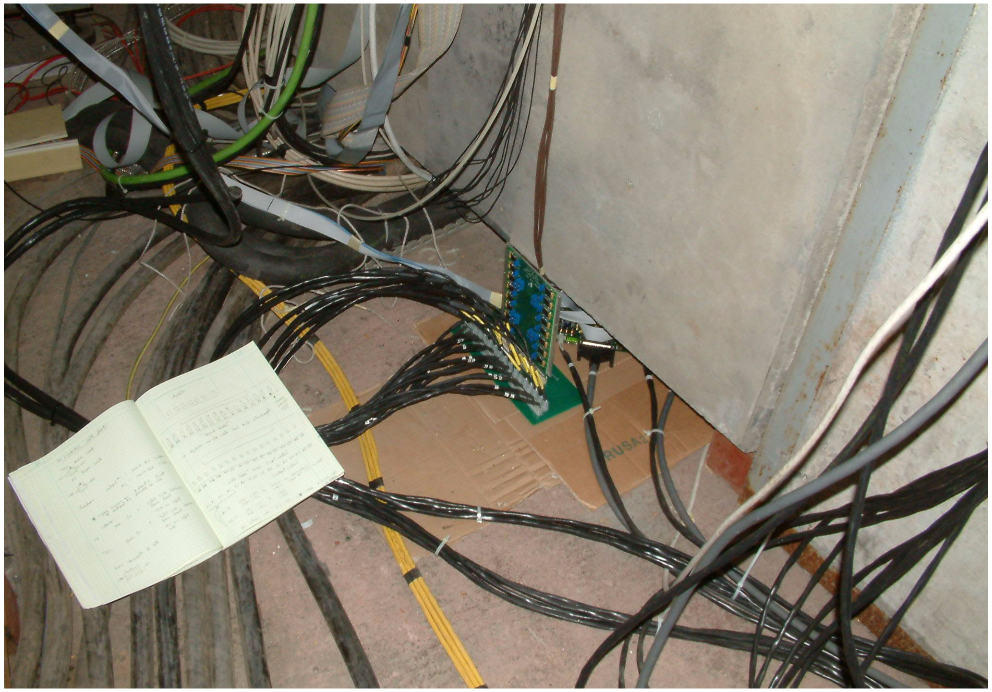
Many thanks to small, but dedicated, team:

- Jocelyn, Petr, Patrick, Fabian, Claudia, John plus module task force organizing module assembly for irradiation.

Summary of Modules for Irradiation

- **BN_11 (M420094)**: IZM-bumped B-chip barrel module with CIS sensor.
- **BN_12 (M420110)**: IZM-bumped A-chip barrel module with CIS sensor.
- **GE_14 (M420096)**: AMS-bumped B-chip barrel module with CIS sensor.
- **GE_18 (M420049)**: AMS-bumped B-chip barrel module with new Tesla sensor.
- **GE_19 (M420097)**: AMS-bumped B-chip barrel module with new Tesla sensor.
- **LBL_8 (M420081)**: AMS-bumped A-chip disk module with CIS sensor.
- **LBL_11 (M420079)**: IZM-bumped B-chip disk module with CIS sensor.
- All modules were equipped with a total micro-cable length of about 60-70cm. For barrel modules, this was a Bonn micro-cable. For disk modules, this was a disk pigtail (10cm), a standard micro-cable (20cm) plus extension micro-cable (30cm).
- All modules were mounted using thermal adhesive on carbon-carbon plates (Genova), which were in turn glued to carbon-fiber plates of the same size as the frame PCB (cut to 173mm in y). Finally, these module units were bolted to the carbon-carbon cooling structures (Wuppertal) using thermal grease. This is a more complex interface than the final detector, but worked reasonably well.
- Cooling system was designed by Jocelyn and Petr, with software from Patrick, and worked quite well, unless it was near the end of a CO2 bottle (biphase flow in long service pipes caused large temperature oscillations). Overall, the system was adequate to keep fully irradiated modules at -7C as measured by module NTC.

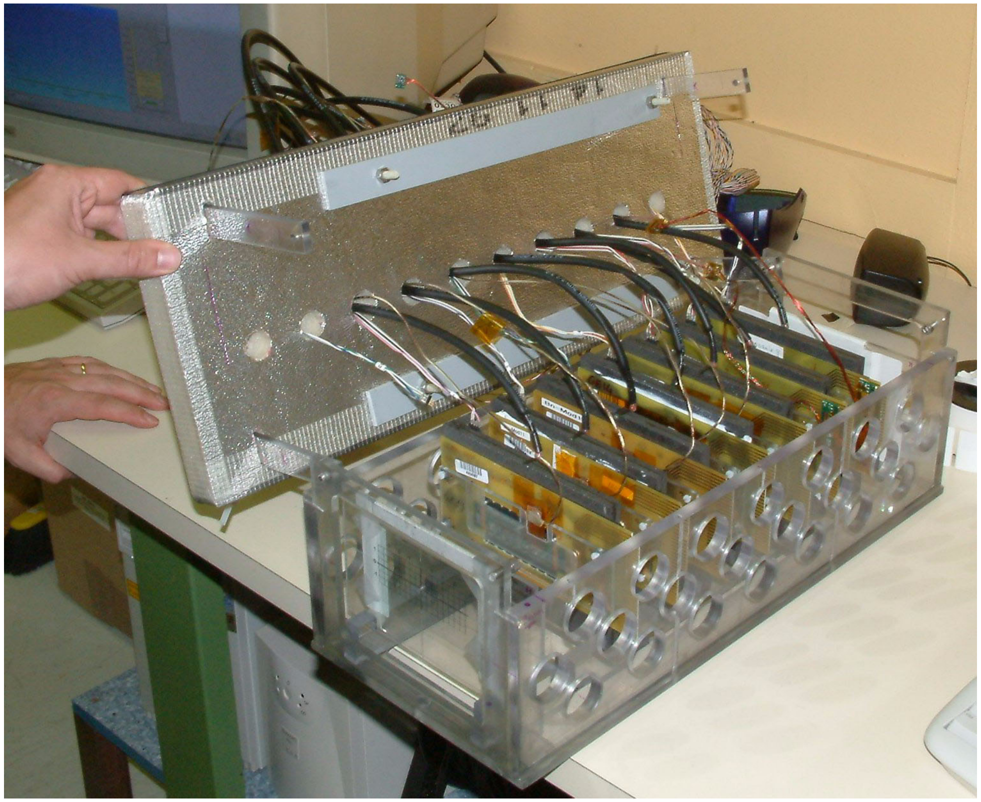
- In order to control low voltage drops on long services from T7 barracks, used Milano regulator board, and remote sensing over “Type 2” cable of length 12m, similar to the real services. The cable provided eight sets of outputs from regulator board, with the last one used to operate LVDS Buffers on PP0 Support board.
- Concerns about temperature of regulator board (we will instrument it next time) caused us to set the LV supplies to 6V instead of the usual 8V. The measured drops were about 1V from supply to regulator and 1V for regulator to PP0. A 6V input left 1V for the regulator itself, and caused the regulator board to run at 50C.
- Al foils, covering the FE chip area of the module, were placed behind the first and last module in the basket. These will be divided into 16 pieces to determine dose.
- Regulators and TPCCs:



TPCC are largely hidden under concrete shielding blocks.

Regulator board is rad-hard, so it could be left out. This was required for cooling and for cable plant.

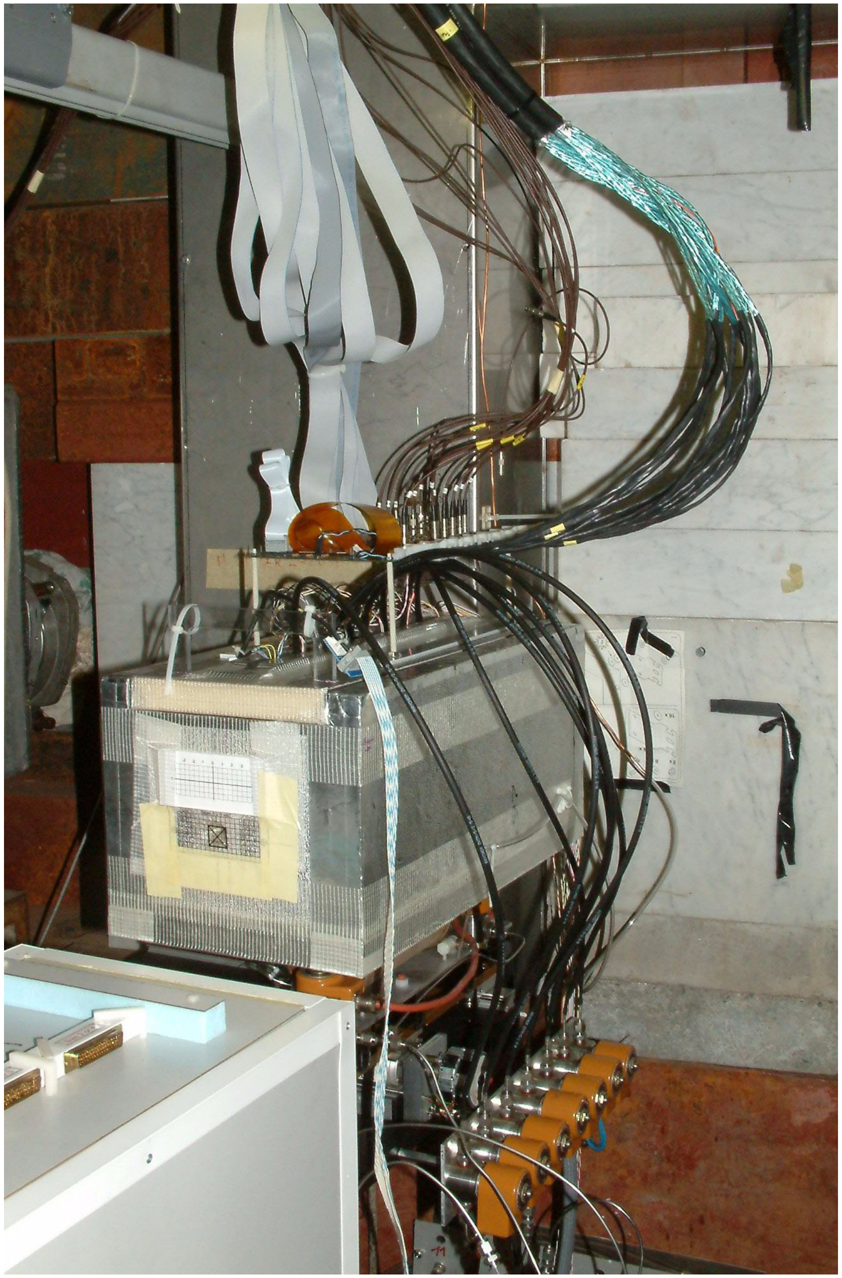
Cold box with modules:



Modules are located in plastic basket, which is suspended from top of box.

PP0 Support card on top of box is crosspoint for all of the electrical services.

Cooling valves are at lower right in beam.



Observations and Lessons:

- Realized that modules from Bonn and Genova had DTO2 polarity swapped, and so they were not compatible with dual link readout with PP0 Support board. However, with the 7m flat cables from the TPCC to the PP0 Support board, it was not possible to operate the LBL modules in dual-80Mbit mode either. Settled on single 80Mbit mode for the irradiation.
- Realized that modules from Genova did not implement the Feb recommendation to disconnect the MCC RSIb signal and connect this trace to the VCal trace on the Flex. Found a workaround in which the VCal from the TPCC was set to 1.6V to ensure that no MCC reset was generated.
- Encountered significant problems with first generation pigtails on barrel modules. One Bonn module lost its HV connection, but was rescued by careful intervention by Fabian. One Genova module lost its NTC connection. Hopefully this difficulty will be solved by improved pigtail plus stiffener design in new generation of modules.
- LBL micro-cables were delicate prototypes. Also, they did not properly implement remote sensing, so regulators were adjusted to provide a higher output voltage. Miraculously, no problems were encountered with these cables, but significant work remains to develop production micro-cable.

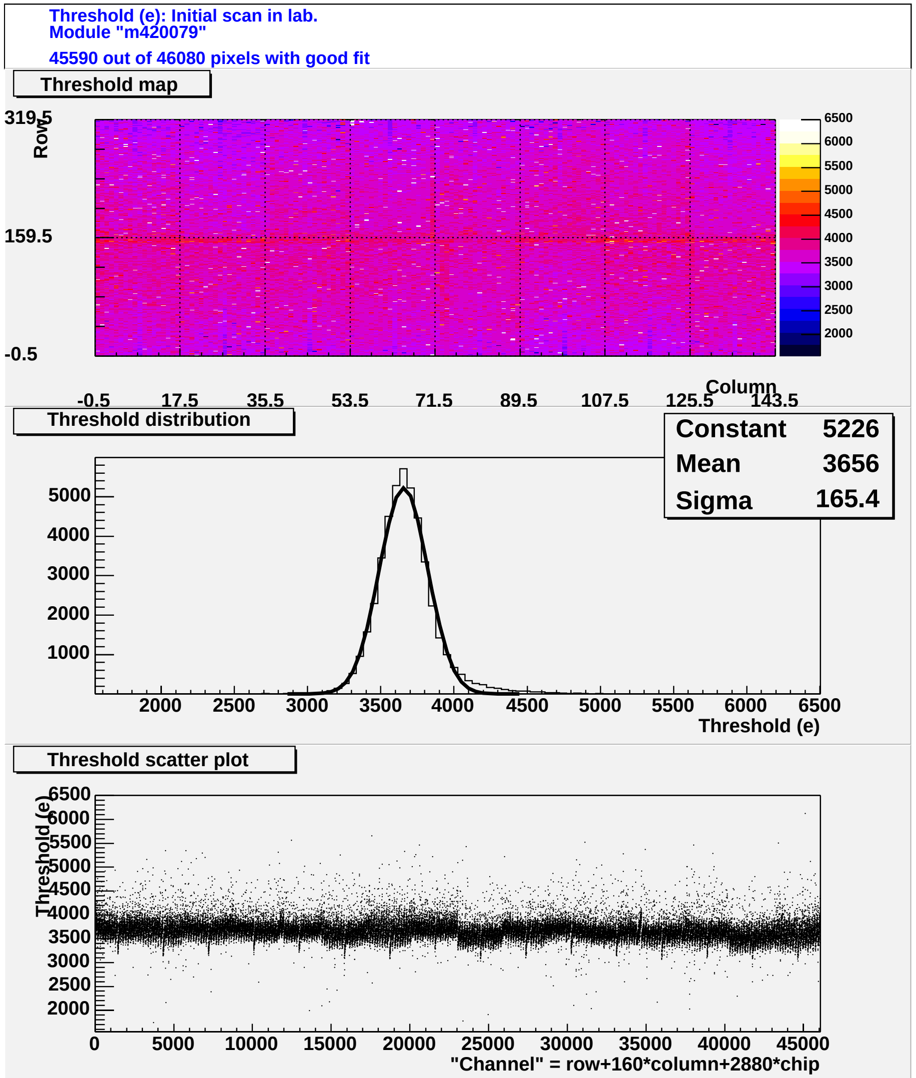
- Initial testing in barracks with short (1m) cable between Agilent lab supplies and Milano regulator board produced high noise level on all assemblies. Looking at VDDA line on scope, saw 20mV peak to peak oscillations with frequency in range of 200KHz to 400KHz. This was a new board with current compensation scheme, and large input filters (almost 50μF). Fortunately, using a longer cable (several meters) eliminated the problem, and there was no problem with the real 25m cables from the T7 barracks to the regulator board. This type of problem had been previously reported for a Wiener supply with remote sense capability (even if the capability was not used). The new Agilent supplies also have this capability, even though it was not used. This is something to watch carefully in the future (proximity of remote sense feedback time constants in input supplies to similar time constants in regulator remote sense).
- Temperature of carbon cooling plate (as measured by Pt1000) was regulated to be between -12C and -17C (depending on the module) in order to get -7C on the module NTC. Based on disk sector system tests, expect about 5C ΔT between coolant and module NTC, and good uniformity. Larger differences here related to multiple interfaces ?

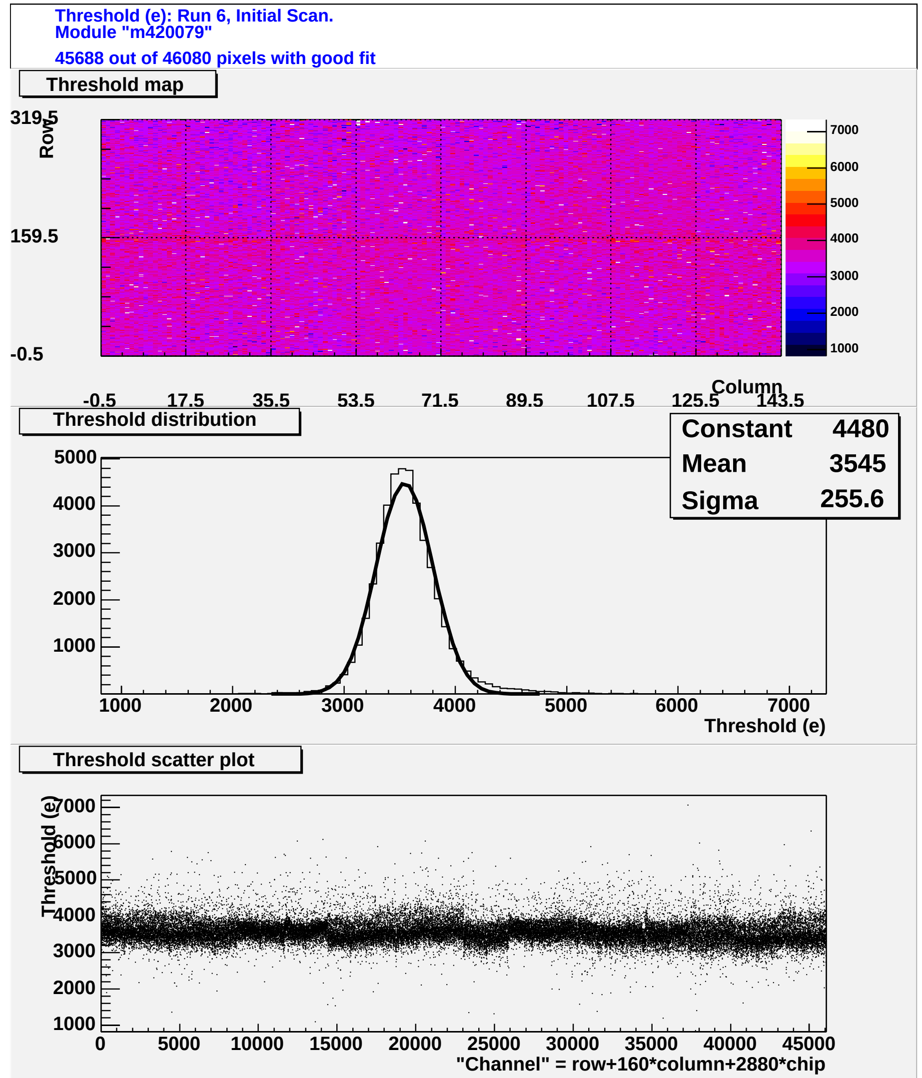
Dosimetry:

- First readings from Al foils imply an average dose of 1.1 x 10^{15} p/cm^2. This would imply a total average dose of only 30MRad. Initial SEC calibration gave total dose of about 9.1 10^{15} p/cm^2, so scanning efficiency would be 1/9, which seems too low. For now, use a normalization of about twice this value...

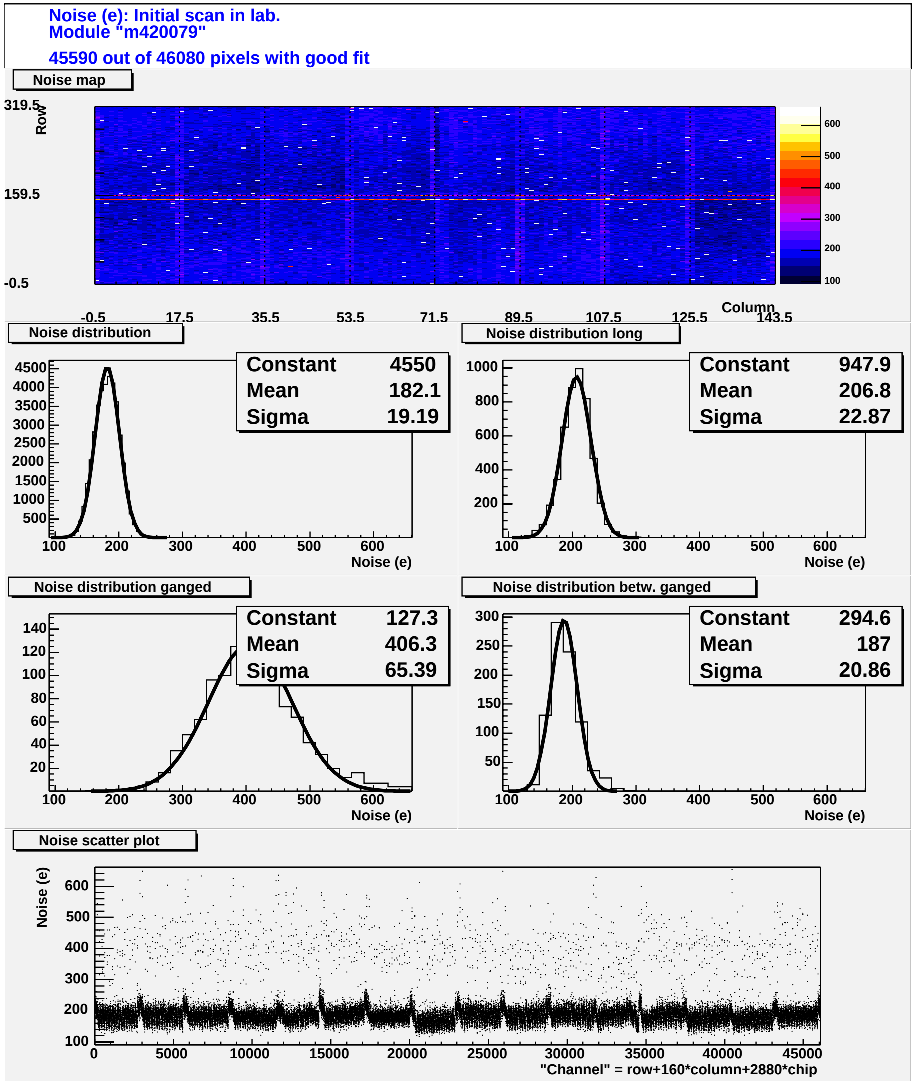
Threshold and Noise Studies

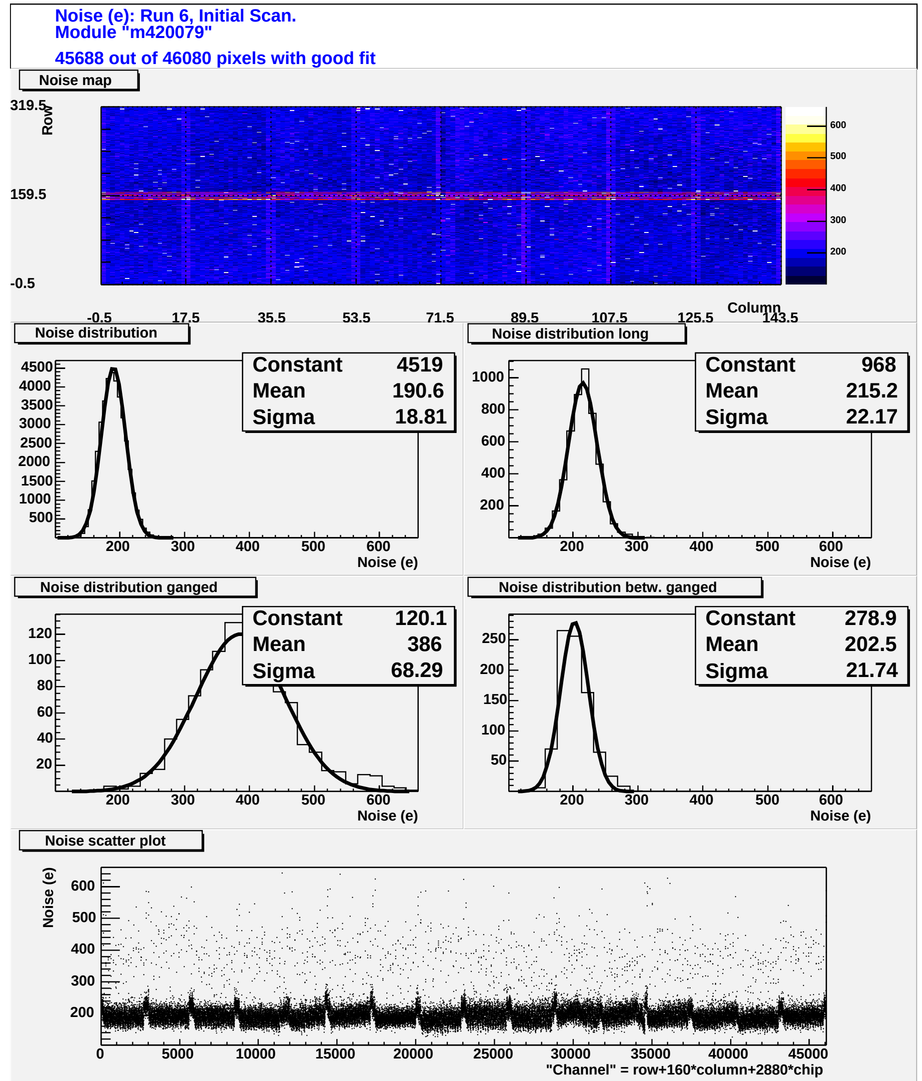
- Initially, all modules were tuned at room temperature, with good dispersion. Some modules had both TDAC and FDAC tuned. Operation at -7C increased the threshold dispersion (left is in LBL lab, right is with box installed in T7):



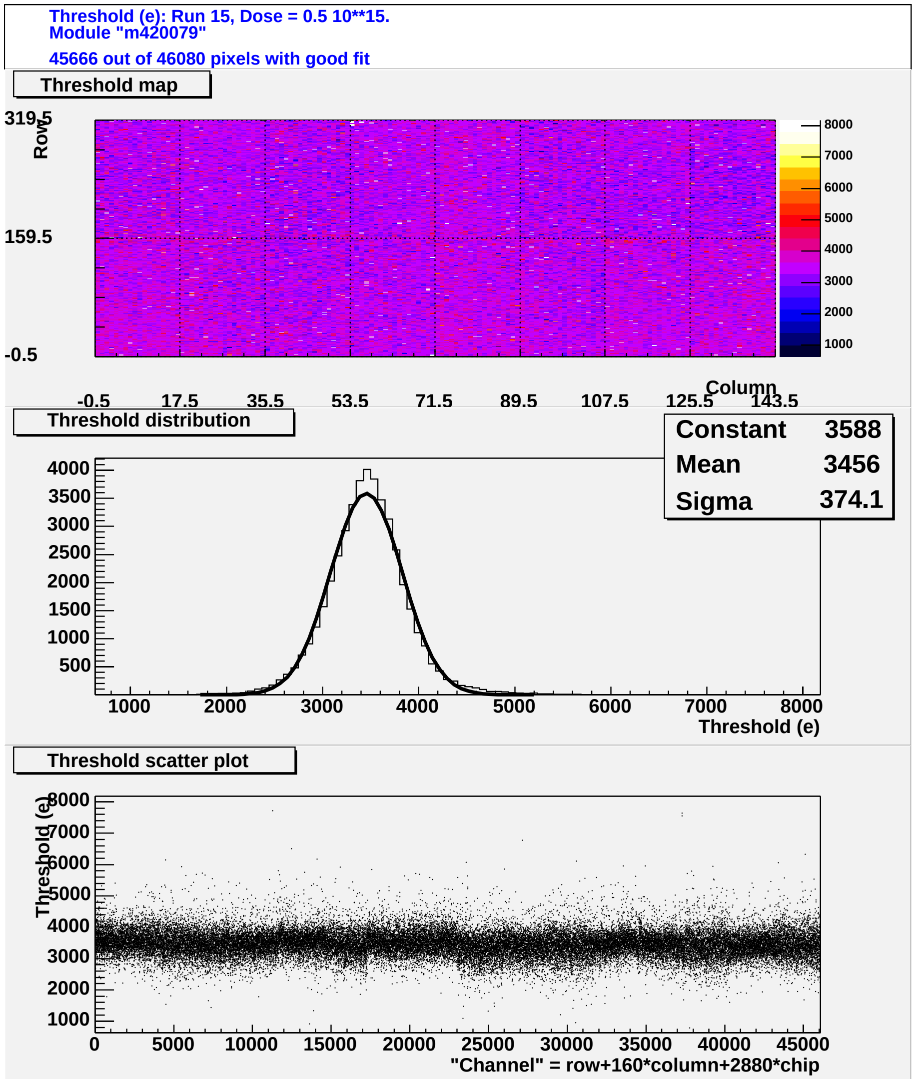


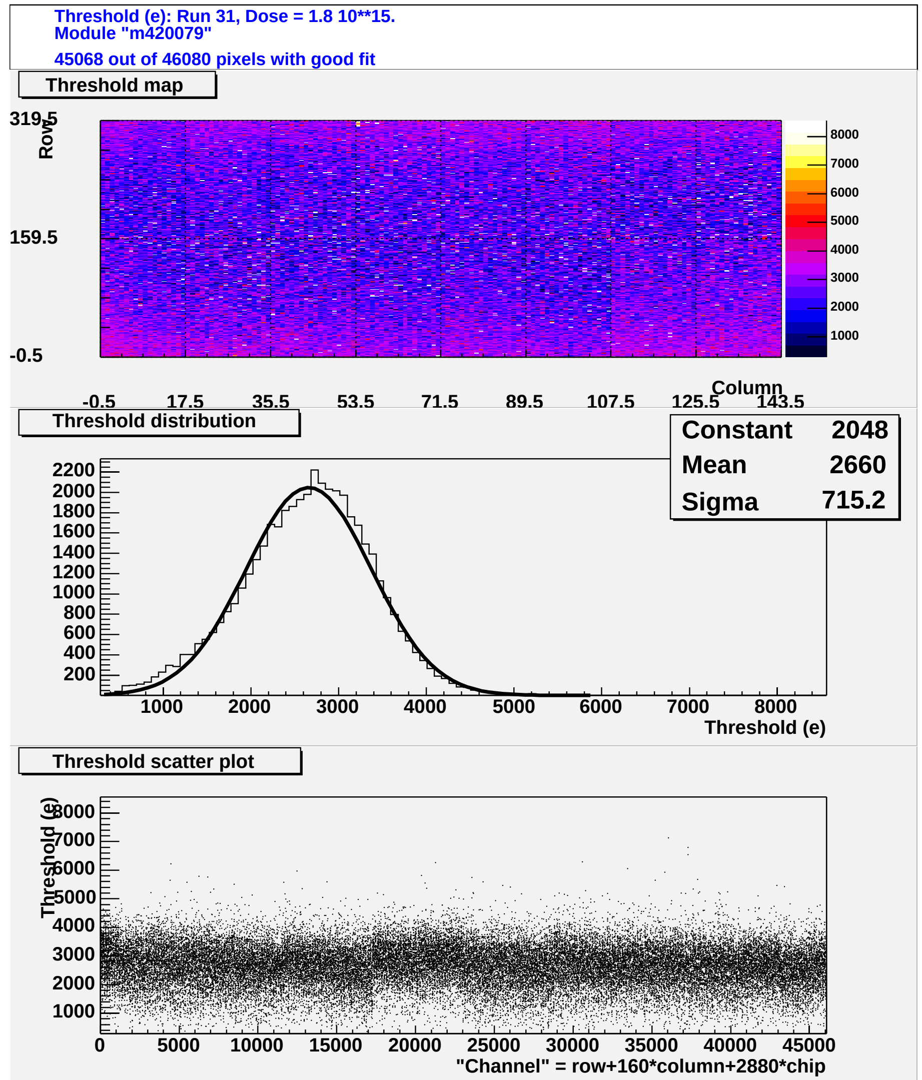
- Noise performance, once regulator oscillation was “cured” by using long input power cables, was almost identical to that in the lab (left in LBL lab, right installed in T7 at -7C). For example, normal pixels had mean 182e on left, 191e on right):



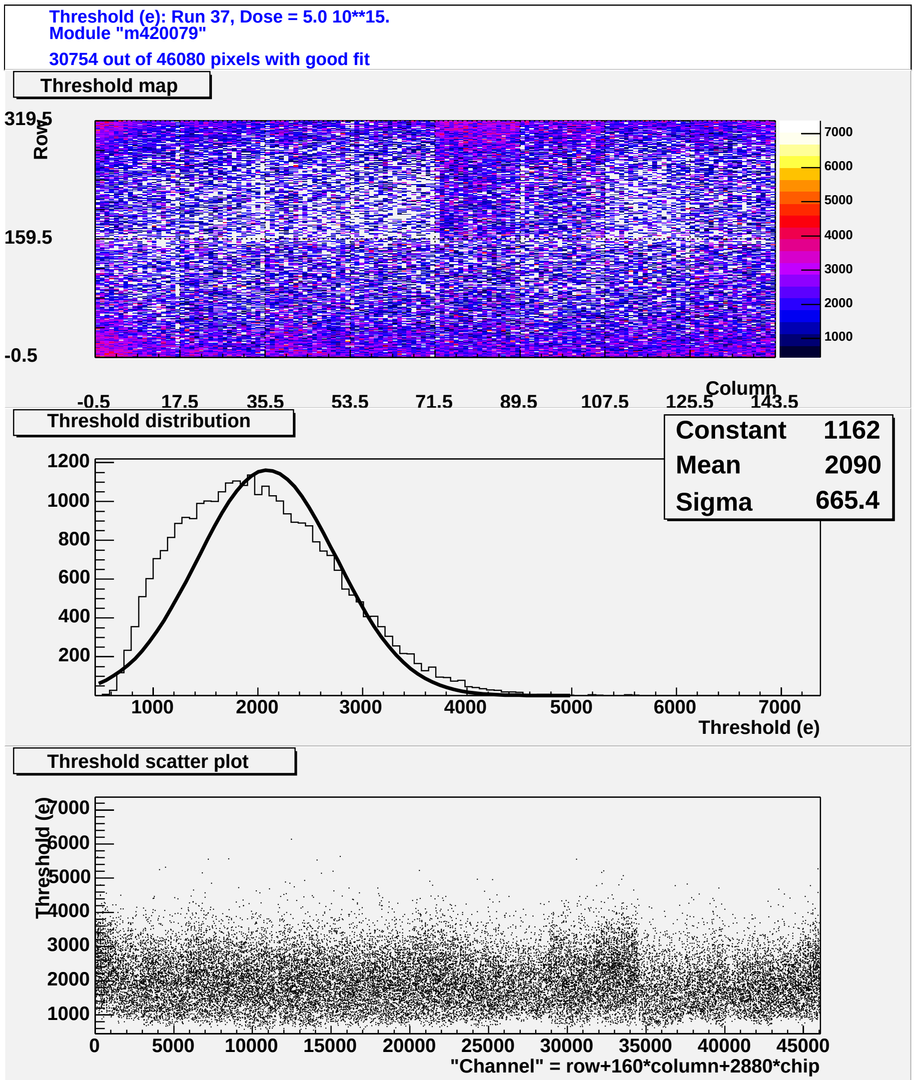


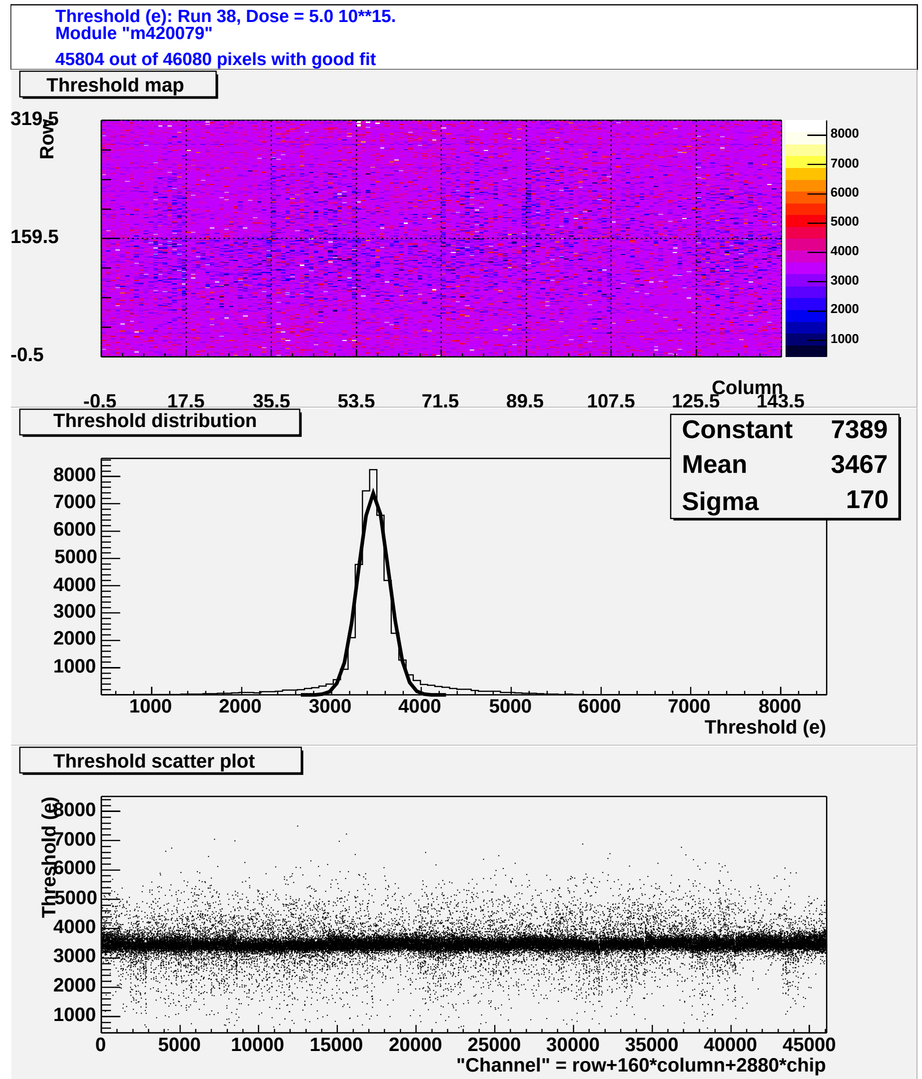
- Threshold dispersion increased with irradiation. Dosimetry at this time is just total SEC count. Estimate about 7MRad per 10^{15} protons seen by SEC, but real normalization awaits the measurements of Al foils. Left is than 3-4MRad, right is about 15MRad:



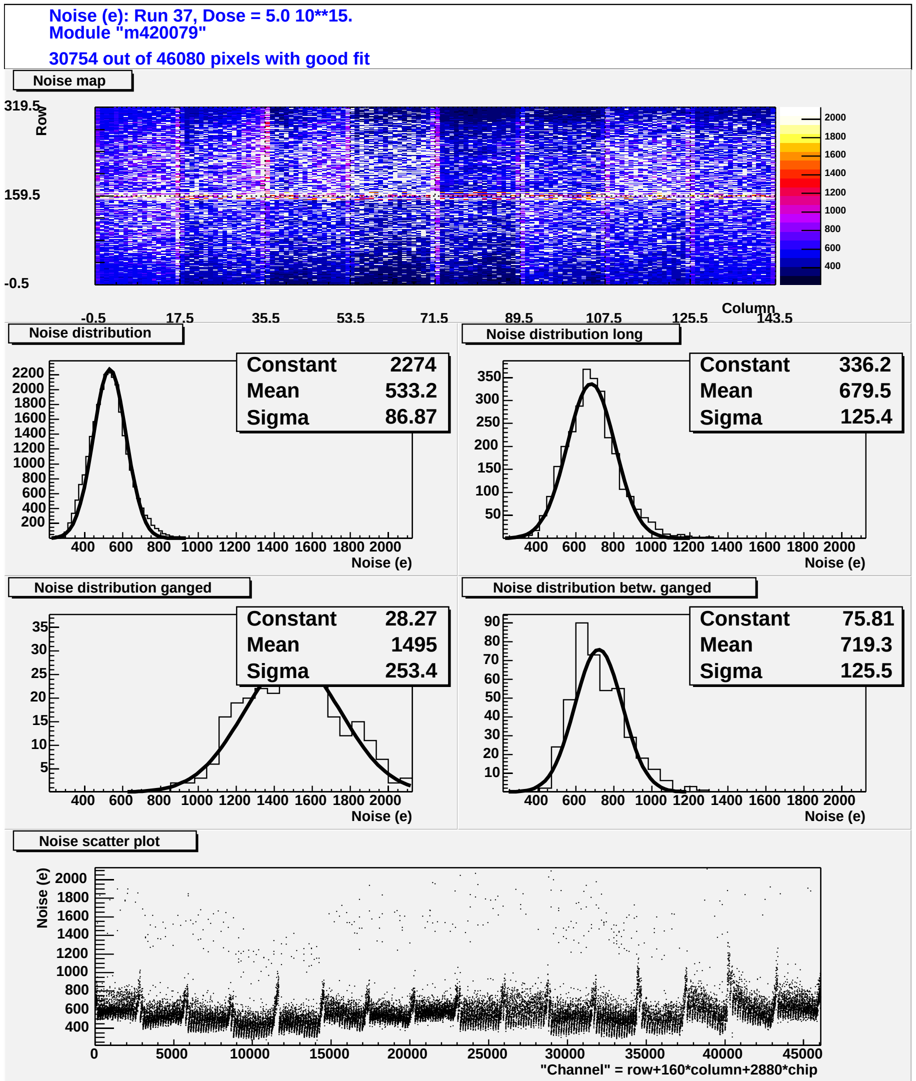


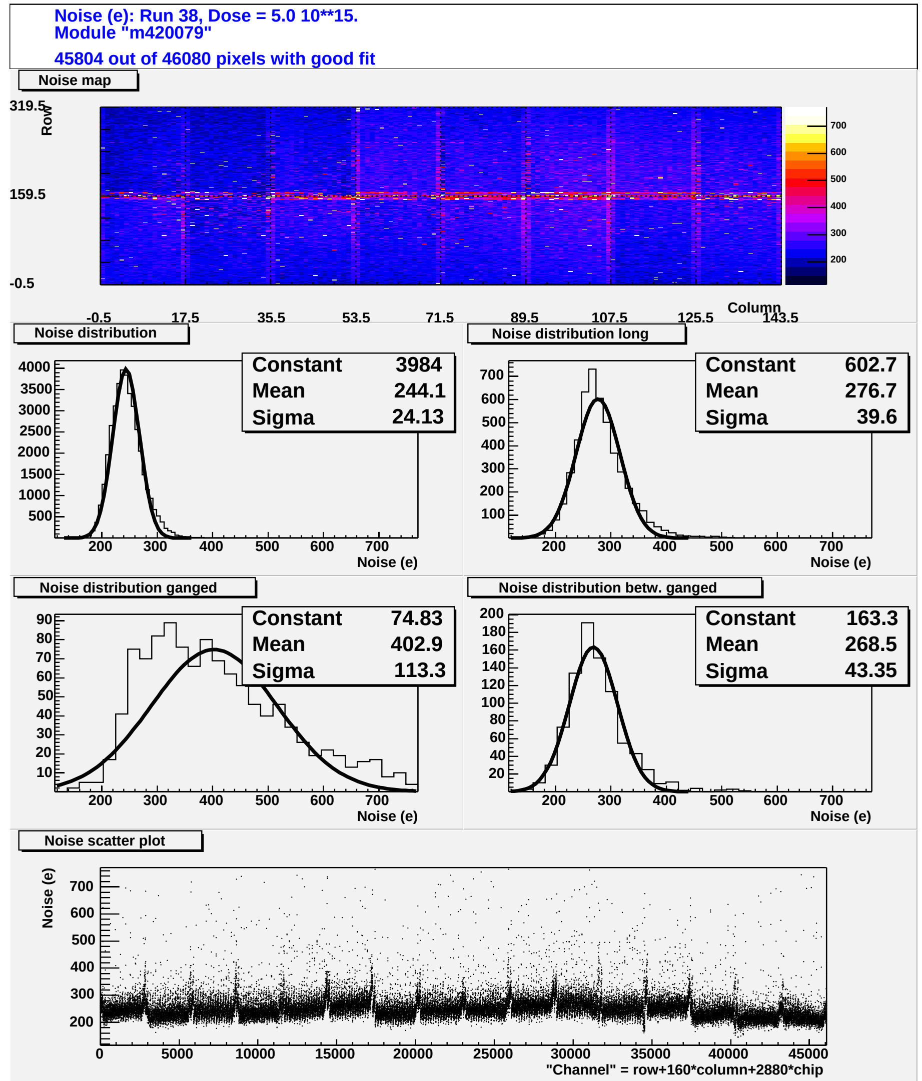
- After acquiring about half of the total dose (about 35MRad ?), two modules were chosen for re-tuning. One was GE_19 (new Tesla) and one was LBL_11 (CIS reference). The threshold distributions before and after re-tuning are shown here, and indicate that the re-tune should have been done with higher ITrimTh setting:



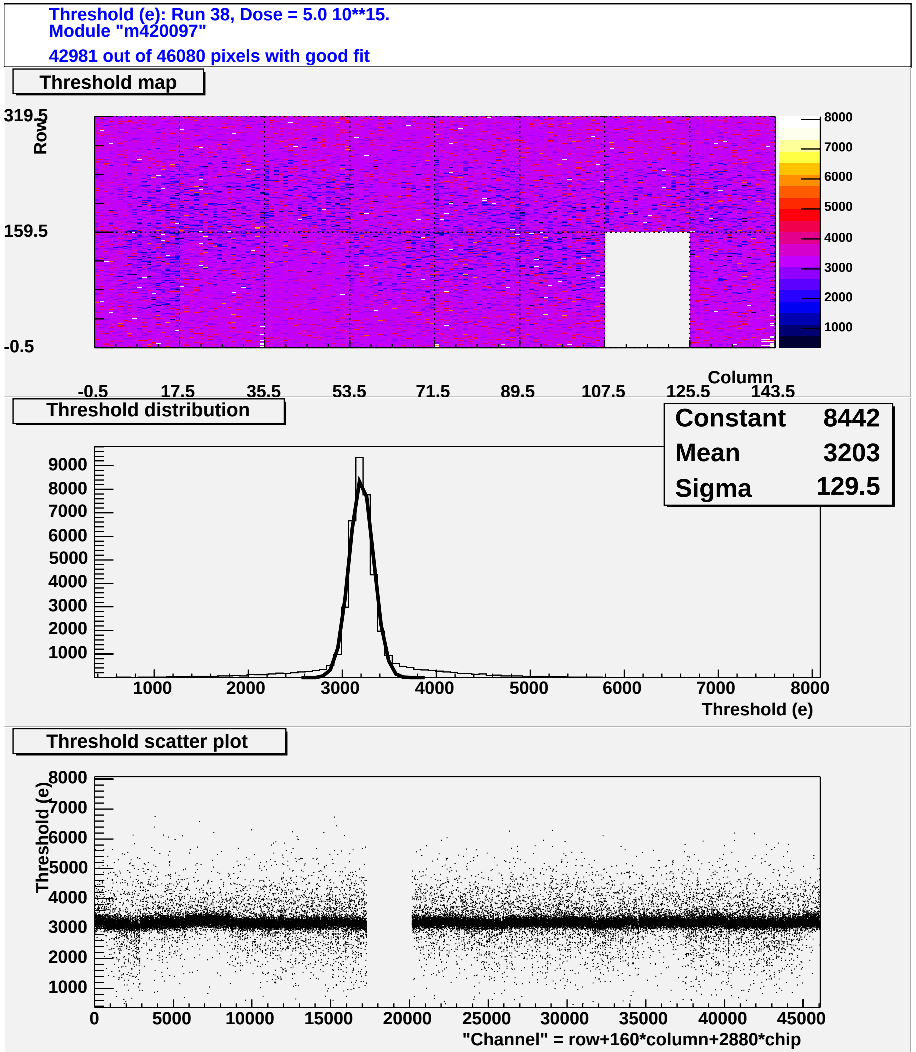


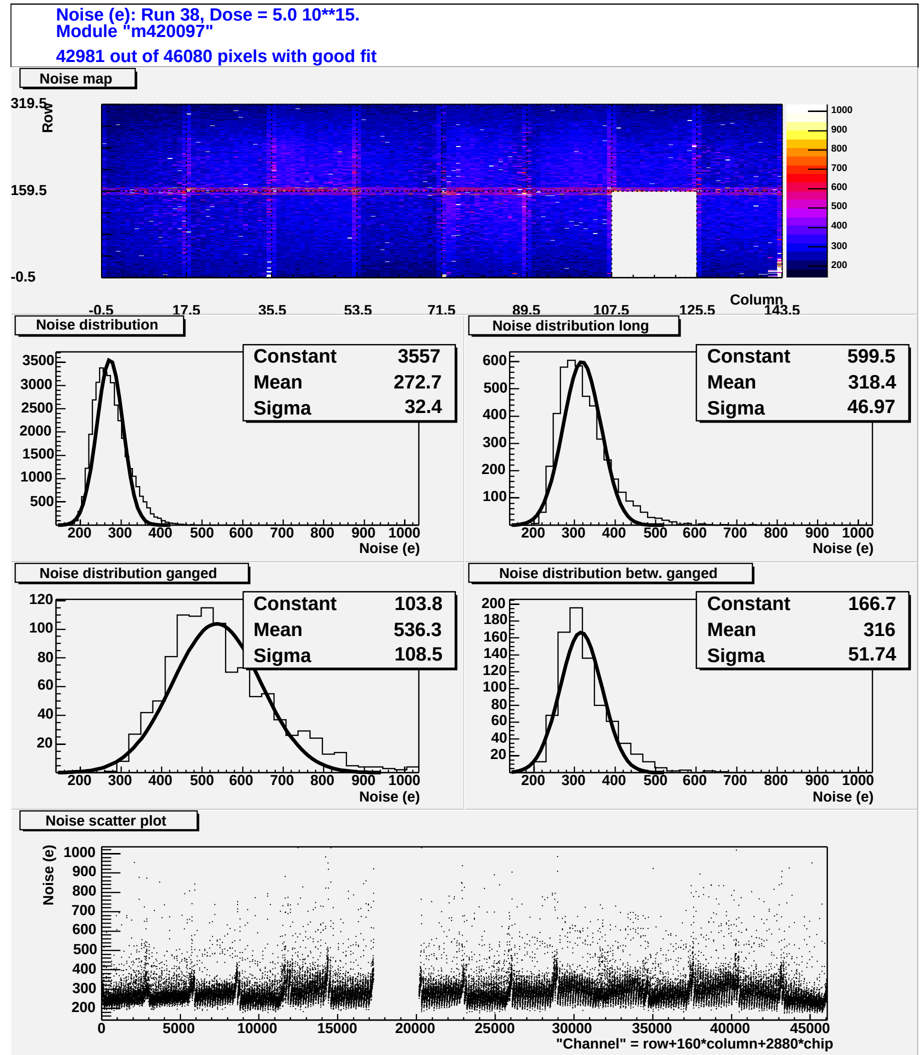
- Noise measurements with large threshold dispersion are essentially useless, but after tuning, noise measurement agrees with expectations after increase in leakage current (about 10-20nA per pixel):



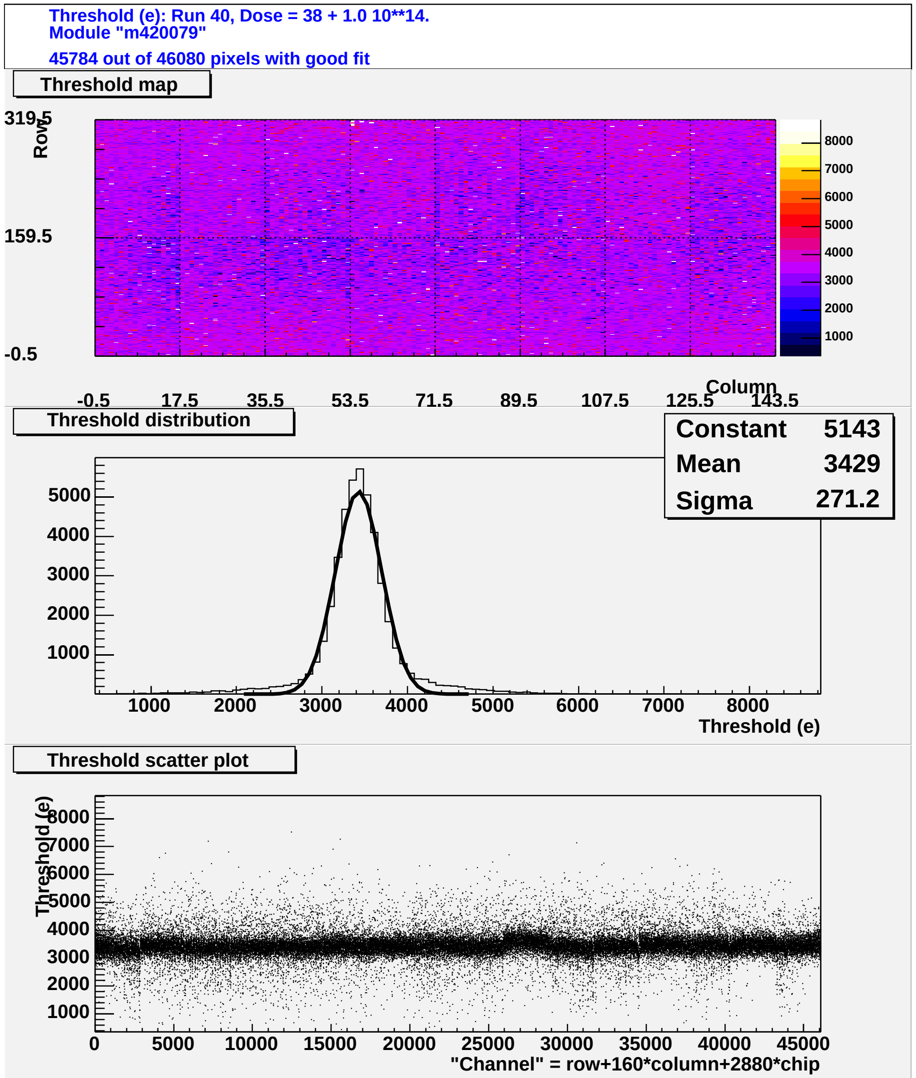


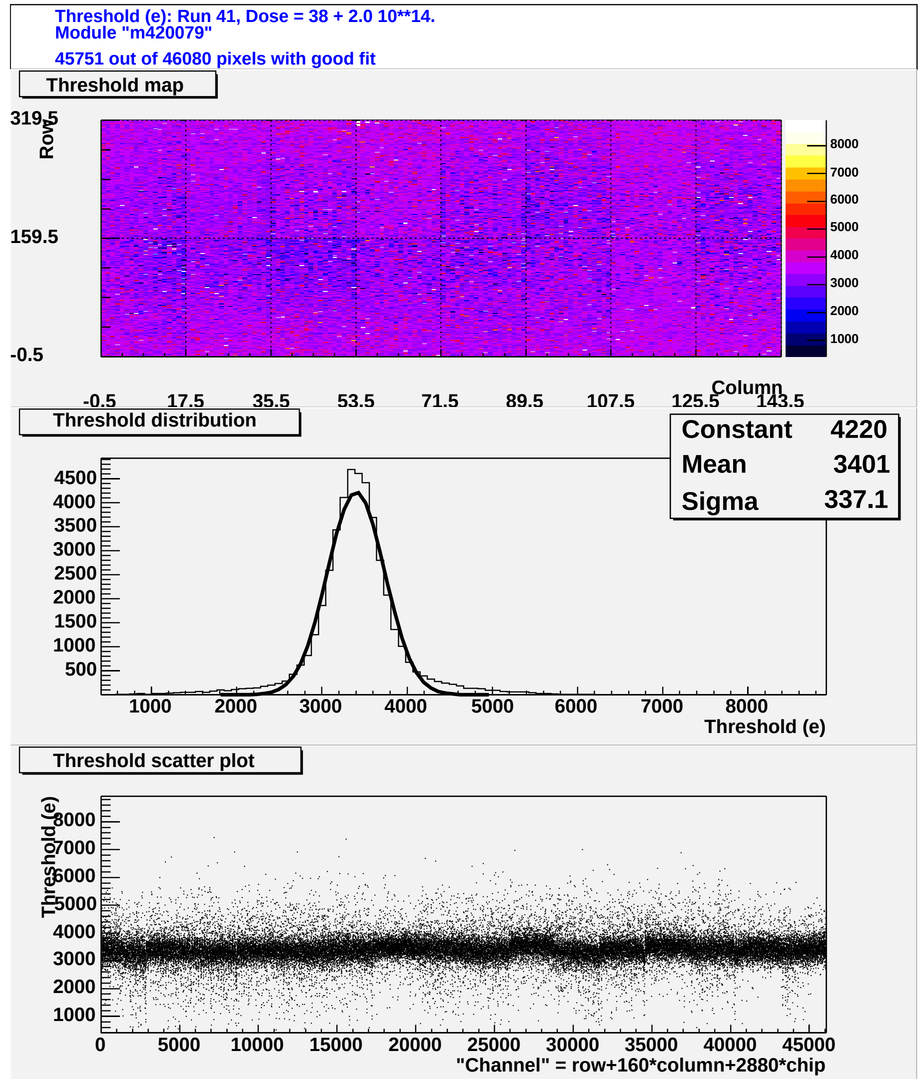
- Performance of GE_19 after re-tuning is very similar. Threshold retuned to similar dispersion with long tails due to small ITrimTh. Noise is similar, but slightly larger, than seen in IZM/CIS assembly. However, there is no sign of the very poor noise performance seen last year with irradiated Tesla:





- Re-dispersion of the threshold happens quickly. As observed at LBL for FE-I1, re-dispersion does not depend on total dose, so similar effects are seen for initial irradiation and continued irradiation after large dose. Left plots are for about 1MRad increment and right plots are for about 2MRad increment after retuning:





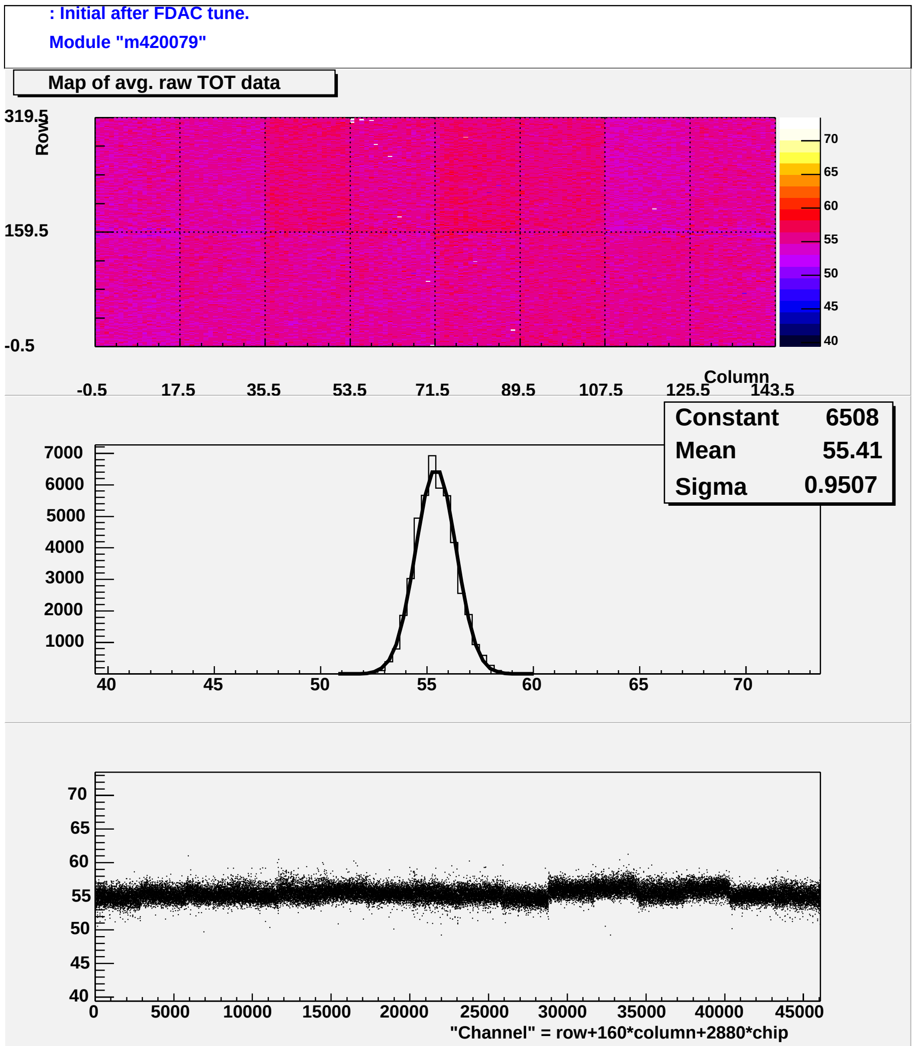
- Table of dispersions for LBL_11 and GE_19 after re-tuning:

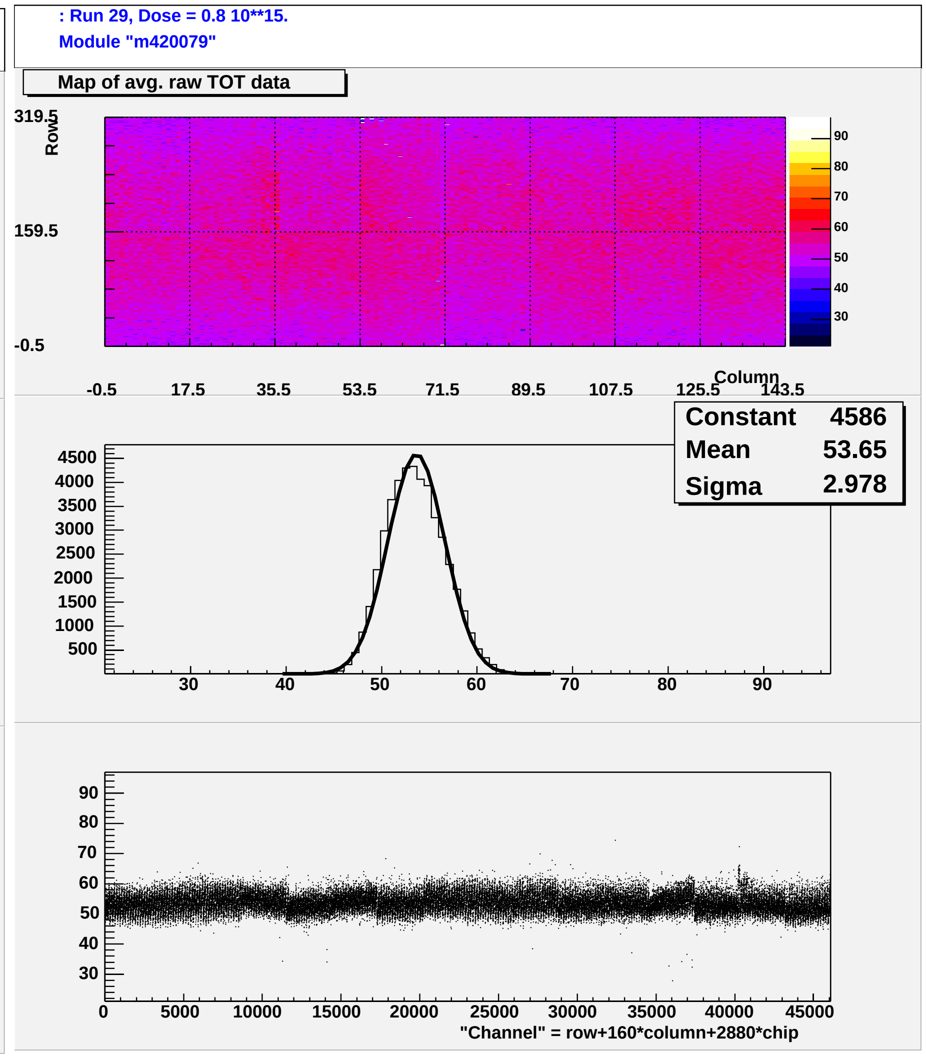
Incremental Dose	LBL_11 Threshold	GE_11 Threshold
$5.0\ 10^{15}$	m = 3467e σ = 170e	m = 3203e σ = 130e
$5.0\ 10^{15} + 0.4\ 10^{14}$	m = 3448e σ = 230e	m = 3175e σ = 171e
$5.0\ 10^{15} + 1.0\ 10^{14}$	m = 3429e σ = 271e	m = 3164e σ = 213e
$5.0\ 10^{15} + 2.0\ 10^{14}$	m = 3401e σ = 337e	m = 3157e σ = 256e
$5.0\ 10^{15} + 4.5\ 10^{14}$	m = 3479e σ = 403e	m = 3273e σ = 346e
$5.0\ 10^{15} + 4.1\ 10^{15}$	m = 3062e σ = 870e	m = 3041e σ = 822e

- Nominally, 10^{14} corresponds to about 0.8MRad at PS. A dispersion above about 300e starts to be a serious nuisance, and would almost certainly require re-tuning.
- Therefore, predict that re-tuning will be needed every 1-2 MRad, or about once every 1-2 weeks for the B-layer.

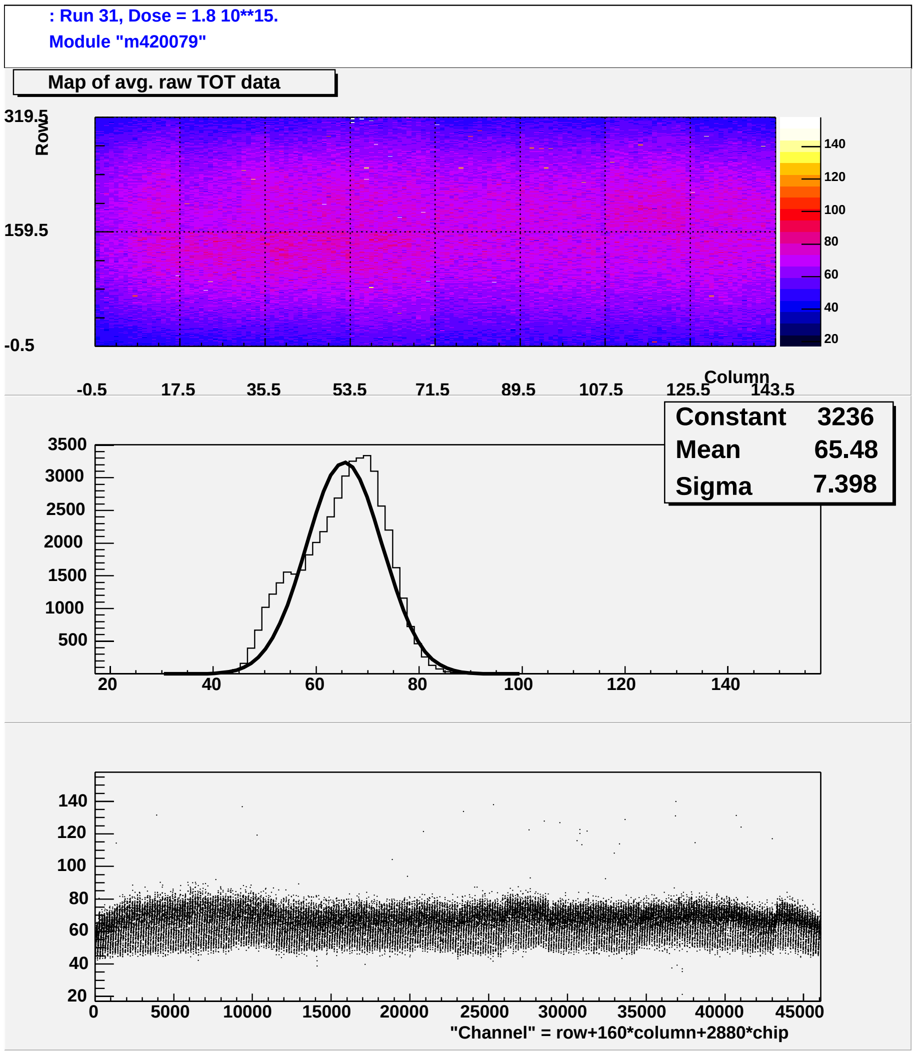
TOT Studies

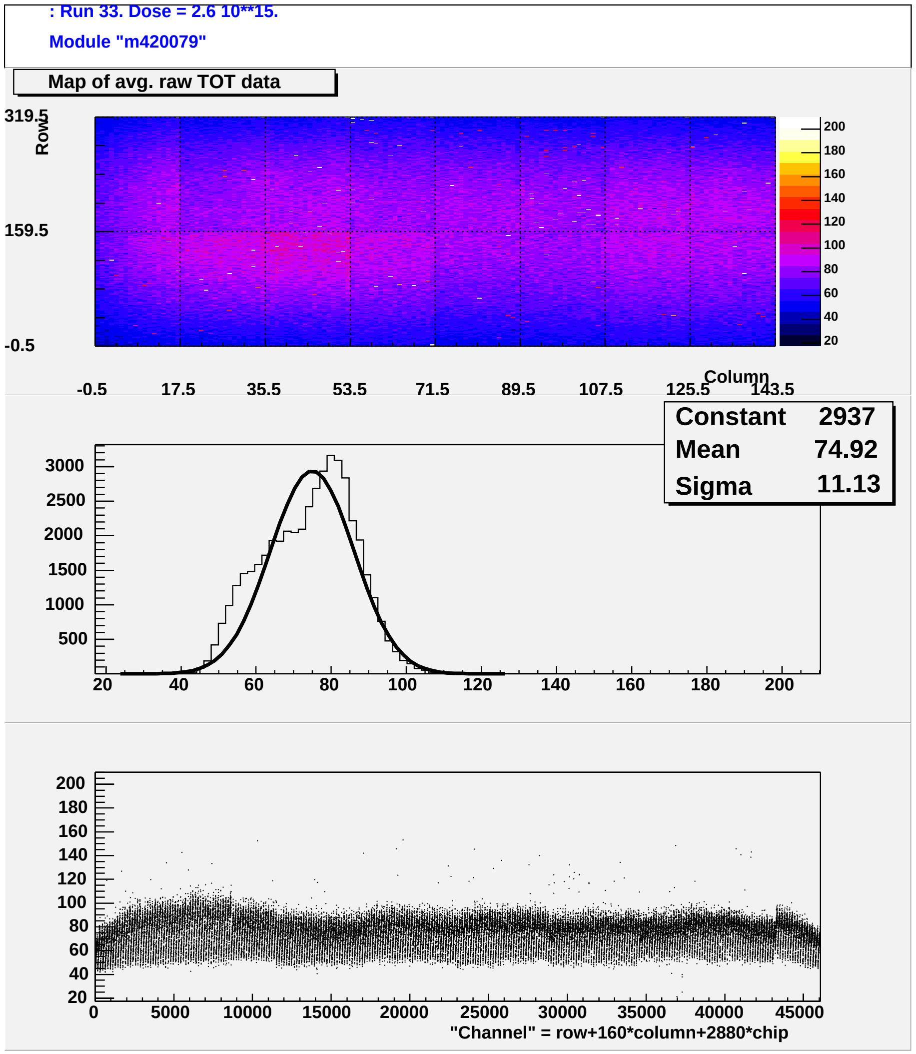
Look at LBL_11, for which FDACs were tuned to give mean TOT about 55 for 20Ke. Use injection of 25 events with 20Ke to study evolution of TOT performance with dose. Initial dispersion of 2% increases to about 6% after dose of about 5MRad.



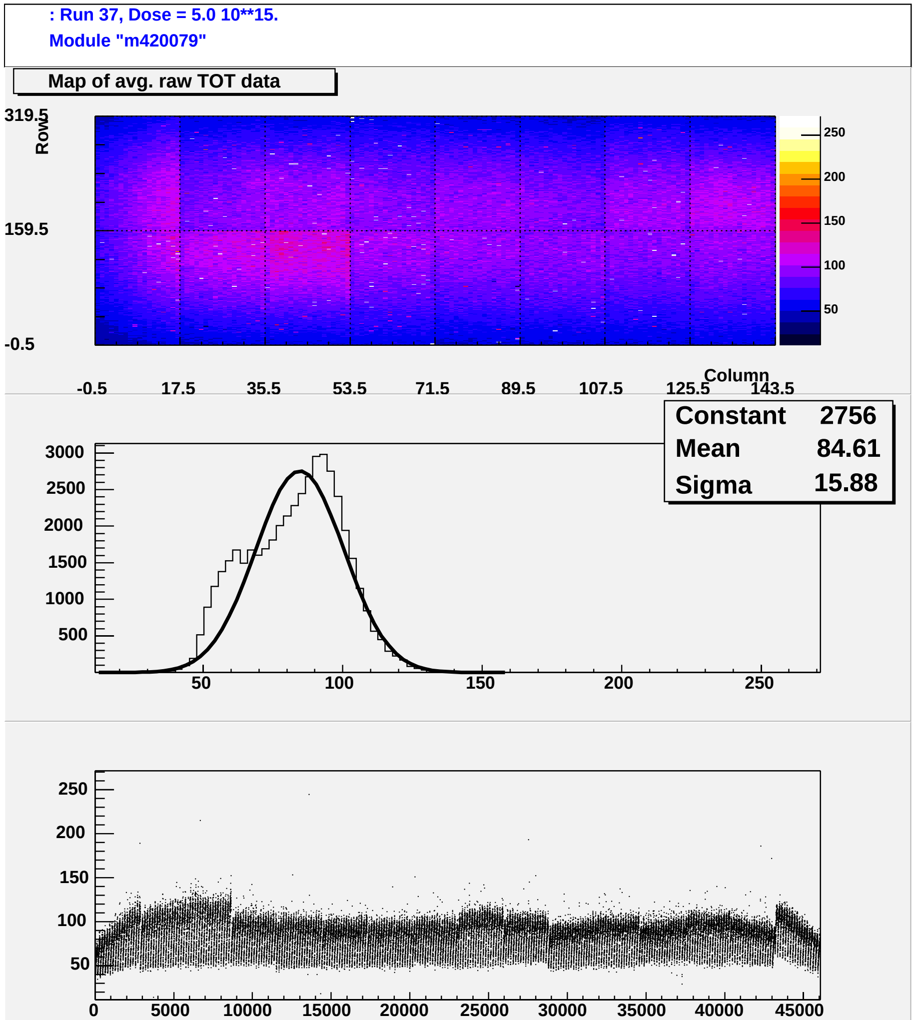


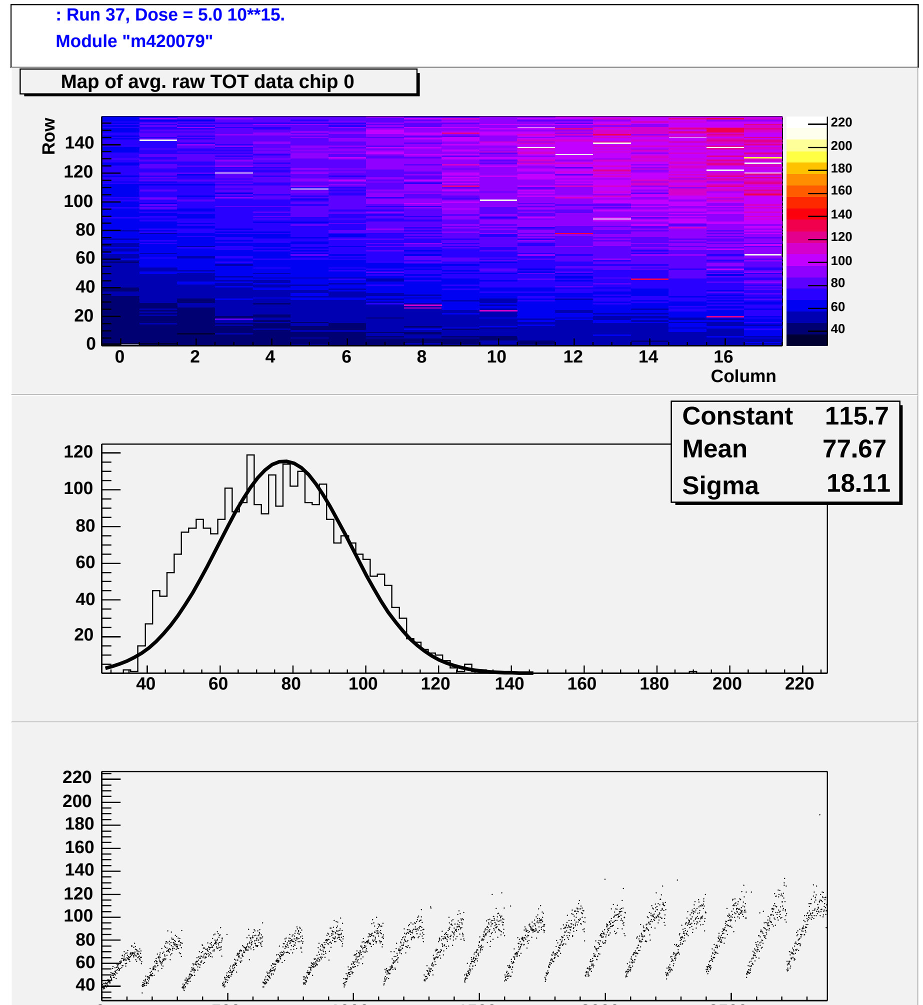
As dose continues to increase, begin to see sudden increase in TOT in high dose regions of module. Left plot is for about 14MRad, right plot is about 18MRad. TOT dispersion occurs more slowly with dose than threshold dispersion, but would still want to retune every 5-10MRad in order to avoid problems:





- Plot of TOT behavior just before threshold re-tune. Show expanded plot for a single chip as well to indicate large variations due to dose. TOT range for 20Ke is 40 - 100 counts. Plots correspond to dose of about 35MRad:

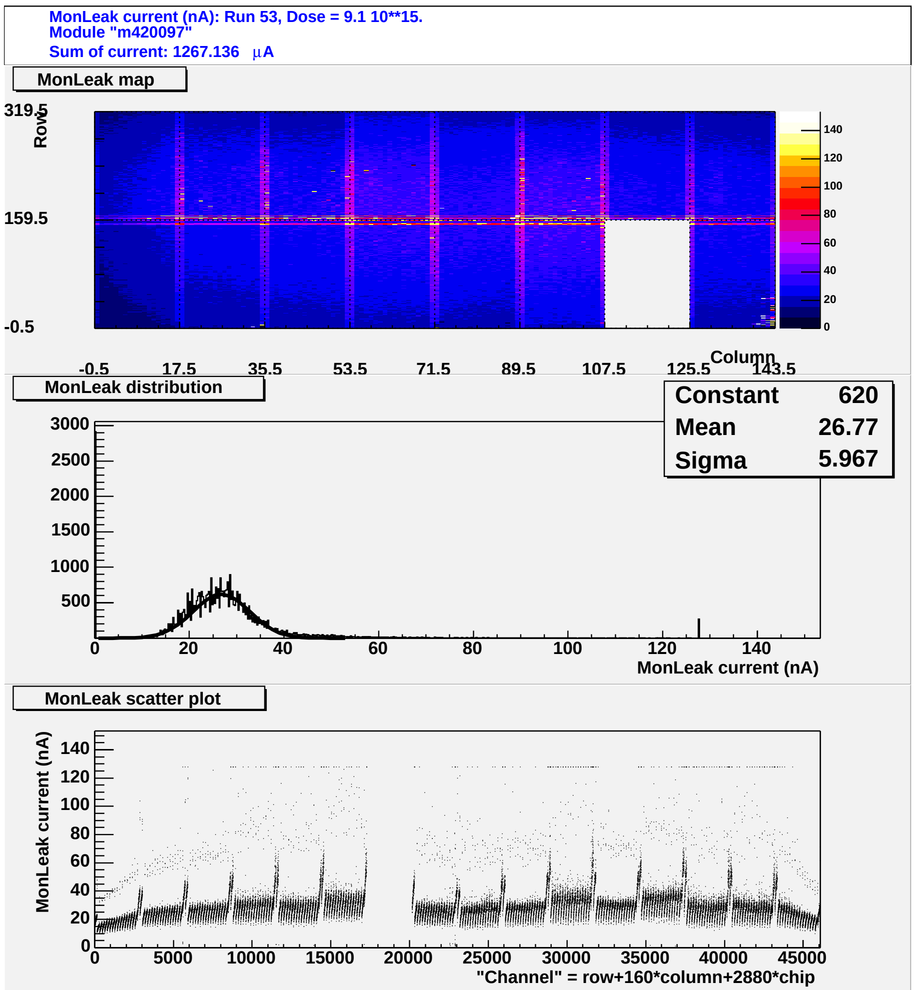


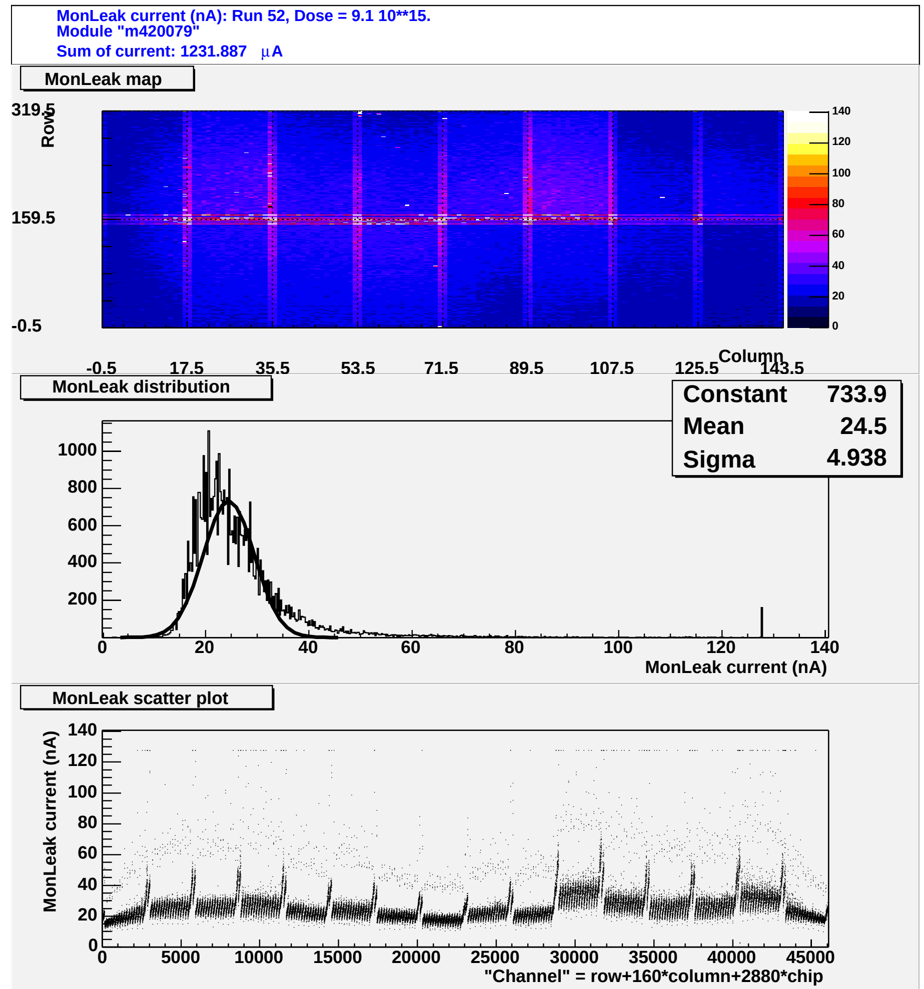


- Initial experience with re-tuning of FDACs suggests that the DAC range may not be adequate after irradiation. Further study needed in lab.

Leakage Current

Plot Monleak current for two modules (GE_19 and LBL_11) at end of irradiation period. Very non-uniform dose is apparent, due to lack of 2D scanning hardware. Additional non-uniformities arise from modest temperature stability during roughly 15 minute MonLeak scan (NTC recorded each chip during scan, see +/- 1-2C variations).





SEU Effects

- Repeated measurements done last year, except this year we used a GPIB scaler and a VME I/O Register to synchronize with PS spills (to make sure register read/write did not coincide with a spill) and to accumulate the SEC count acquired during a given SEU measurement. Will improve this for next run.
- TurboDAQ was modified so that FE measurements always updated MCC configuration to avoid having MCC SEU effects adding to the FE SEU rate.
- Bit flip rates were measured in the Global Shift Register, the Global Latches, and the Pixel Latches by leaving known data patterns sitting in the registers or latches, reading them back, and searching for changes.
- Little analysis done so far, but rates seem similar to those measured in 2002.
- In addition, tried various module-level scans to see how well they would keep running. In particular, long (50K event) digital scans of complete module were done, both “synchronized” with spill and “anti-synchronized” with spill.
- Finally, tried rather demanding self-trigger run for LBL_11. Runs of length about 100K events would often end successfully. If they ended well, would only see small number of pixels with plus/minus a few hits. Other runs ended with missing column pairs or missing chips. Finally, some runs ended with all event building blocked.
- PS operated at 4.5 10^{13} p/hour, corresponding to one week of LHC operation at B-layer radius for each hour of at the PS. A 10 minute MTBF for full detector would require one module to operate properly for about one hour at the PS.

- Observed problems were roughly what was expected. Occasional loss of all data during scans could be explained by MCC upsets and FE Global Register upsets (recall that MCC will hang forever if a given FE chip stops producing EOE words). MTBF for a module was probably a few minutes, but most problems could presumably be fixed by re-writing MCC Registers (10μs) and the FE Global Registers (roughly 1msec per module). Expect I2 generation to be much better, and to exceed the requirements for operation in ATLAS.
- John added code to re-initialize the MCC every mask step during a scan, and also to regularly update the MCC configuration during a self-trigger scan. Have the strong impression that many problems were “fixed” or “minimized” using this technique, suggesting MCC is more SEU-sensitive than FE chips. However, in general, not enough SEU data was taken this run, due to lack of time for operators to sit and carry out runs.
- Also added code to keep re-initializing TPCC, because after about one week of operation, these boards were “resetting” more and more frequently. Not clear if this was a thermal or a radiation dose effect (total dose was huge, corresponding to about 240MRad !) Problem needs further investigation, and may reflect a design weakness in TPCC.

Summary

- Carried out first successful full module irradiation. This was the largest ATLAS pixel system (320K channels) operated up to this time.
- Due to failure of septum power supply, PS was operated at 20 GeV, allowing much higher intensity than expected. Initial dosimetry suggests that modules received, on average, only 30MRad and 0.55 10^{15} n equiv. This seems too low.
- After discovering basic electrical incompatibilities, everything else went fairly smoothly, with reliable, low-noise operation of modules.
- Major total dose effects are on the threshold and its dispersion, and the TOT scale and its dispersion. Threshold control works well (albeit slightly differently) after a large dose. TOT control looks more fragile, but further study is needed.
- First operation of modules during very high fluences indicates that there are a number of SEU-soft aspects of the operation, which require regular re-initialization to keep a module operating properly. However, the problems were always managable by standard software techniques. Expect this will be much improved for I2 generation.
- Towards the end of the run, after departure of experts, Petr observed problems with operation of two modules. Will investigate in the lab.
- Additional issue for ISEG HV supplies was occasional observation of trips during spills, although average current was far from limit. Suggests preference for “constant current” limit instead of trip in final power supplies.